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# USING MOTION PICTURES FOR DATA COLLECTION ON PRESCRIBED BURNING EXPERIMENTS

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## ABSTRACT

*A simple, inexpensive, and relatively accurate photographic method for data collection is described. Objects of interest are triangulated from films taken simultaneously at two camera positions. Accumulated synchronization and measurement errors amounted to 0.2-0.5 m. The method appears adequate for most applications on field experiments of prescribed burning.*

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Most fire researchers use cameras on prescribed burns and experimental fires. They also collect time-lapse motion pictures of many of these fires. However, while some objective information might be taken from such photographs, the full potential of photography as a data collection system is apparently overlooked in many experiments.

Fire phenomena are often highly transitory but produce visible effects which can be captured on film for later reconstruction and analysis. Fritschen et al.[1] used photographs to study flame structure, speed, and approximate temperature. Palmer[2] used photographs to study smoke plume volumes from fires of different sizes and intensities. We were interested in smoke plume velocities and volume flows resulting from small test fires and found that photography was, by far, the simplest and cheapest option available to us.

Our method, described below, is only one possibility for incorporating motion pictures into a data collection system. Other studies or objectives might require different techniques. We offer this discussion as one example of photographic data collection which could be applied to similar situations.

*Application of Photography to the Bend, Oregon, Experiments*

A number of separate experiments were conducted using twenty-four 0.01-acre (0.004-ha) fuelbeds burned near Bend, Oregon. Our purpose was to investigate the amounts of certain smoke constituents produced (particulate matter, hydrocarbon gases, etc.) as a function of fire intensity and treatment of fuels with flame retardant chemicals. We sampled concentrations of these constituents at various points within the plume; but without some idea of plume volume flow, we could not relate these concentrations to the total amounts of these constituents produced by the fires. Our experiments were designed to obtain estimates of these plume volume flows from motion picture photography.

The fuelbeds were 21 feet (6.4 m) square and built on cleared, level ground. The cameras were located primarily on the basis of distance from the fuelbed and lighting. We were interested in the lowest portion of the smoke plumes, so the camera positions were never more than 200 feet (61 m) from the fuelbed. At this distance, the plume occupied the center of the field of view. Under these conditions, the methods described below were sufficiently accurate for our purposes. However, they may not be appropriate if cameras are located at greater distances, differing elevations, or where measurements are made near the edges of the field of view.

We estimated the cross-sectional area of the plume by determining its width at a fixed height from two camera views and assuming an elliptical cross section. We then estimated volume flow from this cross-sectional area and the plume velocity, which we calculated by tracking either individual smoke puffs or neutral-buoyancy balloons entrained in the plume. The procedures used to locate the cameras and to make the calculations are described below.

*Procedure for Locating Camera Positions*

1. Locate two cameras at some convenient distance apart so that all activities of interest occur within the field of view of both cameras. (The lines of sight of the two cameras should intersect at some well-marked reference point.) We

[1]Fritschen, Leo, Harley Bovee, Konrad Buettner, and others. 1970. Slash fire atmospheric pollution. USDA Forest Service Research Paper PNW-97, 42 p. Pacific Northwest Forest & Range Experiment Station, Portland, Oreg. 1970.

[2]Personal communication with Thomas Y. Palmer, USDA Forest Service, Pacific Southwest Forest & Range Experiment Station, Riverside, Calif.

used two 16-mm movie cameras at right angles to and 55 m from the center of the slash pile to be observed.

2. Measure the distance from each camera film plane to the reference point (fig. 1, $d_1$ and $d_2$). Our reference point was a 12-m vertical steel tower marked with alternating 1.5-m green and white stripes.

3. Measure the distance between the two cameras (fig. 1, $d_3$).

4. Finally, measure the distance ($d_r$) from one of the cameras to some object of known length ($R$) in the plane perpendicular to the line of sight, which is visible in the field of view of that camera. We used 1.5-m stripes on the steel tower for ($R$), thus eliminating a separate set of measurements.

Calculations are much easier if all measurements are recorded in the same units. This includes measurements made from the projected film images. Focal lengths of the two camera lenses should ideally be the same, as should lenses used for projecting the film during measurement.

Photograph pairs must be made at or sufficiently near the same instant in time for purposes of the experiment. A pair of solenoid shutter actuators, both triggered by the same pulse, is easy to install if the electrical connections are physically practical.[3] Otherwise, a film speed of 24 frames

[3]Radio-controlled synchronization has been developed and used for this purpose by researchers at the Northern Forest Fire Laboratory (Rod Norum, personal communication).

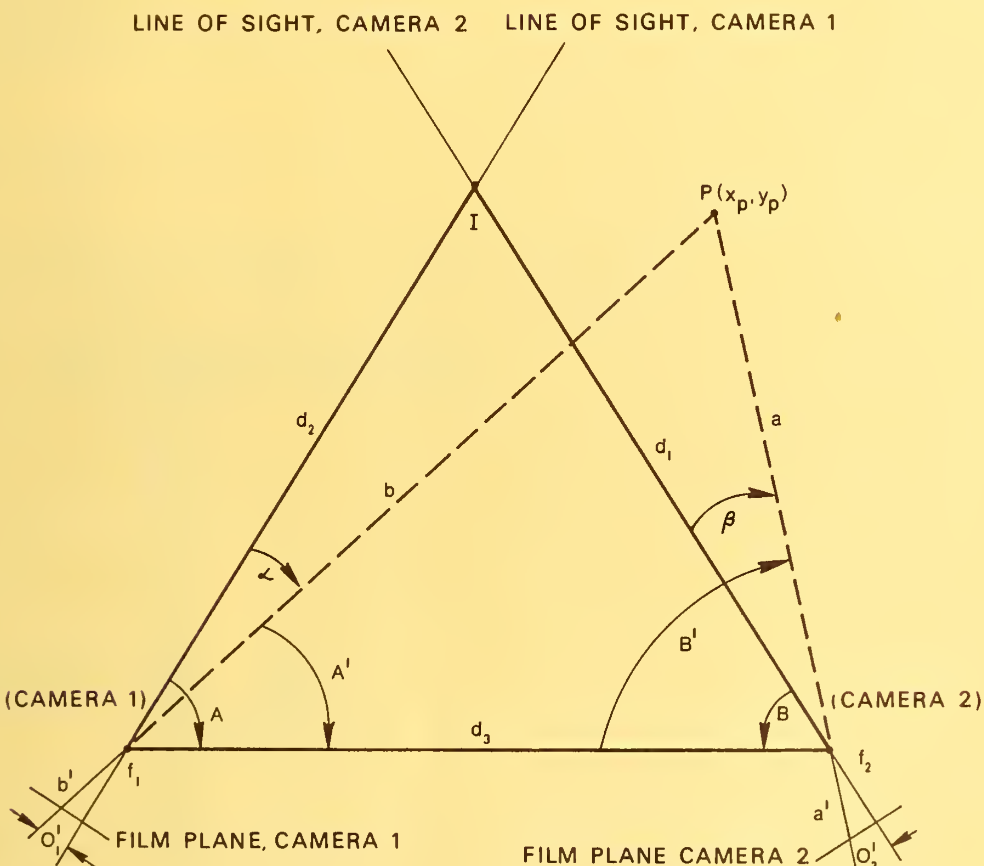


*Figure 1.--Determination of spatial coordinates of point ($X_p$, $Y_p$) by triangulation from two camera views.*

per second and a time marker visible to both cameras are adequate for many purposes. The error caused by inexact synchronization depends on both the frame rate and the velocity of the object of interest across the planes of view of the two cameras. In our work, we detonated about 3 ounces of flash powder which gave a flash usually visible in only one or sometimes two frames of each camera.

*Measurements From Film Images*

All distances are measured from the image of a point of interest (P') to the image of the fixed reference point (I', fig. 2). The horizontal and vertical components of these distances in each camera view are termed offsets and are identified by subscript according to which camera they are measured in (i.e., $O_1$ and $z_1$ are horizontal and vertical offsets, respectively, in a film frame from camera 1). Offset measurements are rapid and easy if the films are projected onto a horizontal rearview surface. We built a special table for this work beneath which we mounted two stop-frame projectors aimed vertically at the table surface (fig. 3). The viewing surface was

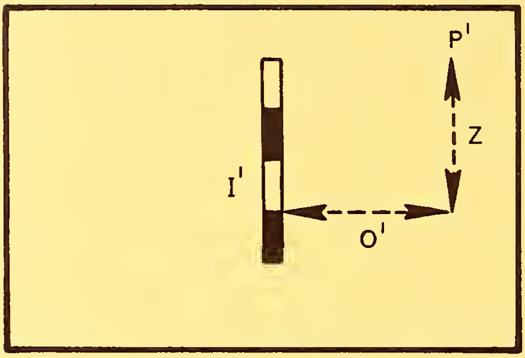


*Figure 2.--Film image measurements. Offset from I' consists of horizontal (x, y) component and vertical (z) component. Film images are identified by prime marks (P' is the photo image of object P in field).*

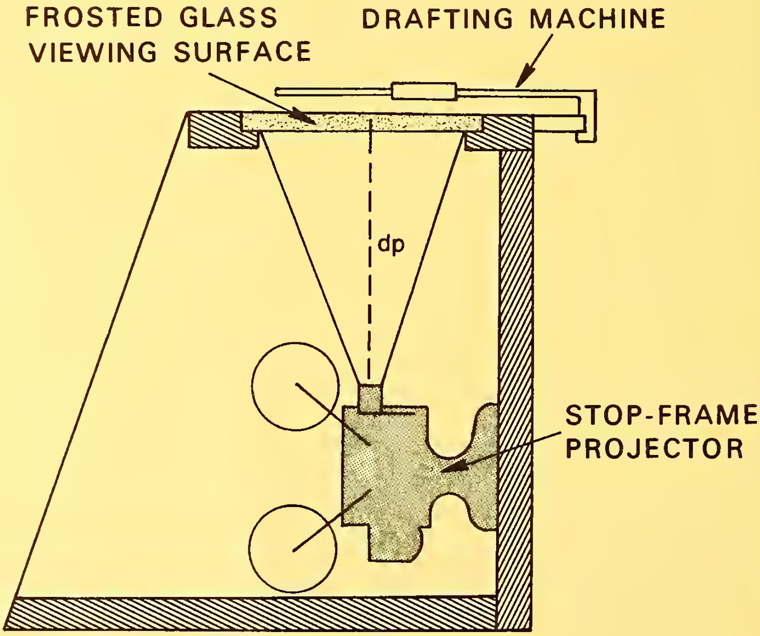


*Figure 3.--Table used for measuring offsets from film images. Distance* dp *is the distance from projector film plane to viewing surface.*

frosted glass and supported a drafting machine. Thus, both camera views of an event could be analyzed at one time. Digitizing equipment and motion analyzers are also well suited to this work.

A sign convention is necessary so that the measurements place the point in the proper quadrant. With this convention, horizontal offsets are given positive values if their position is to the right of the reference point in the projected image.

The vertical distance from the reference point to the object of interest ($Z$) is measured above or below the level line of sight from the camera positions to the reference point. If the object is above the reference point, $Z$ is given a positive value. In our work, the cameras were mounted 1.5 m above flat ground, so the origin for vertical coordinates was a 1.5-m mark on the reference tower. Camera tilt will introduce some error but is not serious for most purposes when the tilt is less than 5°.

*Determining the Coordinates of a Point From the Film Images*

With the distances measured at the site, the triangle $ABI$ (fig. 1) formed by the two camera positions and the reference point can be solved for angles $A$, $B$, and $I$ by the law of cosines and the law of sines.

$$I = \cos^{-1} \frac{d_1^2 + d_2^2 - d_3^2}{2d_1d_2}$$

$$A = \sin^{-1} \frac{d_1}{d_3} \sin I$$

$$B = \sin^{-1} \frac{d_2}{d_3} \sin I$$

Converting film-image measurements to on-the-ground distances requires a proportionality constant for the camera-projector setup. This constant ($f$) is determined from the known reference length ($R$) visible in the film, the length of $R$'s film image ($R'$), and the distance from $R$ to the camera ($d_r$).[4]

$$f = \frac{R'}{R} \cdot d_r$$

For any point $P$ lying within the field of view of both cameras, the new triangle $ABP$ can be solved using the measured offsets $o'_1$ and $O'_2$ and the triangle $ABI$ (fig. 1).

$$A' = A - \alpha \quad \text{and} \quad B' = B + \beta$$

where

$$\alpha = \tan^{-1} \frac{o'_1}{f_1} \quad \text{and} \quad \beta = \tan^{-1} \frac{o'_2}{f_2}$$

then

$$b = d_3 \frac{\sin B'}{\sin (A' + B')} \quad \text{and}$$

$$a = d_3 \frac{\sin A'}{\sin (A' + B')}$$

The horizontal location of point $P$ can now be established by imposing a coordinate system upon $ABP$ such that the coordinates of points $A$ and $B$ are $(0, 0)$ and $(d_3, 0)$, respectively. The coordinates of point $P$ are then $(x_P, y_P)$, where

$$x_p = b \cos A' = d_3 - a \cos B'$$

$$y_p = b \sin A' = a \sin B'$$

The vertical coordinate of point $P$ is found from vertical offset $z_i$ measured in either camera view.

$$Z_p = \frac{b}{b'} \cdot z_1 = \frac{a}{a'} \cdot z_2$$

where

$$b' = \frac{f_1}{\cos \alpha} \quad \text{and} \quad a' = \frac{f_2}{\cos \beta}$$

[4] If the focal lengths of the camera lens ($f_c$) and the projection lens ($f_p$) and the distance from projector film plane to viewing surface ($d_p$) are known, $f$ can also be found from:

$$f = \frac{d_p}{f_p} \cdot f_c \, .$$

*Tracking Moving Objects From Films*

The track of a moving object during a period of observation is reconstructed from the coordinates computed from successive film-frame pairs. Speed or velocity of such an object can then be determined by computing the distance traveled by the object between any two pairs of frames and dividing by the elapsed time between frames. For motion picture cameras, elapsed time in seconds ($T$) equals the difference of the frame numbers of the two pairs used for measurement ($n$), times the reciprocal of the frame rate ($r$, in frames per second), or $T = n/r$ seconds.

*Accuracy of the Method*

Given sufficiently sophisticated equipment and patient attention to detail, almost any photographic method is capable of a high degree of accuracy. However, for highly accurate work, there are more suitable methods. This method is most useful for order-of-magnitude comparisons between observed and predicted phenomena.

The method as here described is subject to three main sources of error:

(1) Errors in measuring the camera-reference and camera-camera distances.

(2) Errors in measuring offsets from the projected film images.

(3) Synchronization errors between the two camera shutters.

Of these three sources, the last is the most difficult to control.

We controlled differences in frame rates between the two cameras with a battery-operated motor drive on each camera. With these motor drives and a suitable visual time marker, the maximum synchronization error should be less than 21.5 ms at 24 frames per second. Many different types of visual time markers can be devised. However, the flash and smoke of detonating flash powder is easy to spot in the films and guarantees locating those two film frames nearest each other in time.

When we know the maximum error in time, the corresponding error in position depends on the speed of the object observed and its path in relation to the plane of view of the camera. Positional errors of objects moving at speeds less than 10 meters per second relative to the plane of view amount to less than 0.2 m and are acceptable for reconstructing most trajectories within a smoke plume.

Errors from the second source occur during offset measurements. Some error is introduced if the axis of the projector lens (fig. 3) is not perpendicular to the viewing surface. Careful preparation of the projection and measuring equipment will minimize this source of error.

Additional errors are introduced as part of the measurements themselves. Even when the objects being measured are easily recognizable, the edges of the measured objects in the projected film images are not precise. Any error in locating these edges results in an error in on-the-ground coordinate locations. In our work, we were usually able to identify the edges of a white 1-m balloon on the projected image with an uncertainty of about 1 mm for a projector arrangement with an $f$ of about 0.5. This magnitude of uncertainty yielded an on-the-ground error of about 10 cm at a distance of 55 m. Accuracy decreases rapidly when measuring objects whose edges are indistinct, such as puffs of smoke. We found it impractical to track individual smoke puffs in the films.

Errors from the final source arise in measuring camera-to-reference and camera-to-camera distances. Errors of a magnitude achievable with ordinary chaining techniques will produce an insignificant error in computed coordinates. However, we recommend that distance $d_3$ be measured rather than turning angle $A$ with anything less accurate than a surveyor's transit.

(Solving a triangle for the length of a side to three significant figures requires angles measured to the nearest 10 minutes.) Accumulated errors in either alinement or distances have the effect of translating the coordinate system and thus lengthening or foreshortening all computed distances. These accumulated errors increase as distance from the camera points to the object increases and are usually most serious at extremes of the field of view.

*Application of the Method*

Using this method, we measured smoke plume velocities above a simulated slash fire, as well as estimating the volume flow rates of gases out of the fire. Figure 4 shows the results of this measurement at three periods during one fire.

We found that the spatial locations of objects could be determined within 0.2 to 0.5 m of their true positions. This accuracy was achieved without elaborate equipment or great expense in either time or money. The results were quite adequate for our purposes and would seem equally adequate for many applications involved in field studies of prescribed burning.

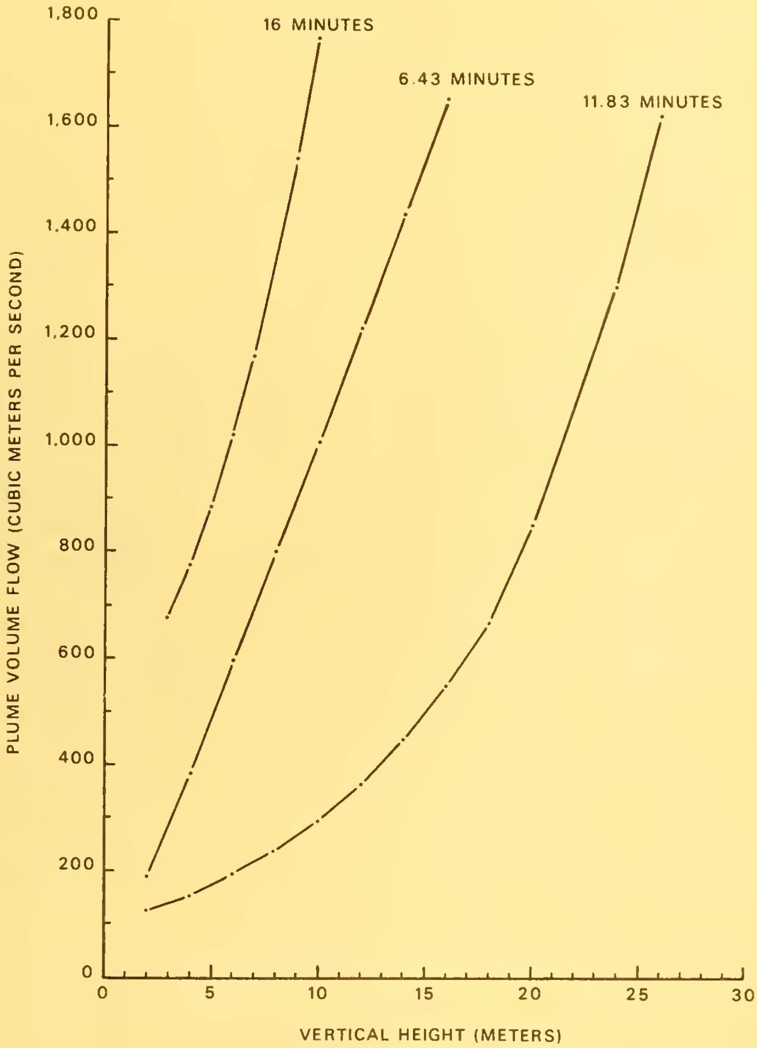


*Figure 4.--Plume volume flow as estimated from speed of neutral buoyancy balloons and dimensions of smoke plume.*

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